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Studying the Behavior of Slender Reinforced Lightweight Concrete Columns Subjected to Eccentric Loads

Dr. Eiad Hafiz Zahran

***Abstract*— Due to technology and research development on concrete compressive strength over the last years, the use of lightweight concrete has proved to be most popular in terms of economy, superior strength, stiffness and durability. However, strength and ductility are generally inversely proportional. Lightweight concrete is a brittle material causing failure to occur suddenly under excessive applied loads. It is also well known, that axial compression concrete elements (i.e. axially compressed) rarely occurs in practice. The stress concentrations caused by eccentric loading, further reduce the strength and ductility of high- strength concrete columns.**

The elastic-plastic behavior of pin-ended reinforced concrete slender columns subjected to biaxially eccentric loads is investigated experimentally and theoretically. The ultimate loads, longitudinal and transverse deformations and the behavior up to failure of the columns are examined in detail.

This paper presents an experimental and analytically (Ansys14) study to investigate the general deformational behavior of eccentrically loaded slender lightweight reinforced concrete columns. Six long scale lightweight columns with 2000 mm height and three cross sections, rectangular, square and circular cross sections. All specimens connected with two end plates were tested under eccentric and no eccentric loads. Different types of lightweight materials were used. Ansys14 has provided useful insight for future application of a finite element package as a method of analysis. To ensure that the finite element model is producing results that can be used for study, any model should be calibrated with good experimental data. This will then provide the proper modeling parameters needed for later use.

***Index Terms*— Ansys14, Lightweight, Slender, Columns, Eccentric.**

I. INTRODUCTION

Columns in building are designed conventionally on the basis of a structural analysis of frames in the planes in which the principal axes of columns are constructed. However, since almost all columns are subjected to biaxial bending, the effects of biaxial bending on the behavior of columns should be investigated. A number of experiments and analyses have been done to investigate the ultimate strength of short reinforced concrete columns under biaxially eccentric loading, and many strength formulations have been proposed for their design.

The column behavior under biaxial loading becomes further complex due to the slenderness effects. There is very little available experimental information of the stability of slender columns. In this paper, fundamental data from biaxially eccentric loading tests of slender columns with square, rectangular and circular cross sections are reported. The objective of this study is to investigate the slenderness effects under biaxial bending on the ultimate strength and the deformation behavior up to the failure of reinforced lightweight concrete columns.

Lightweight concrete is very important to the construction industry due to its cost effective and numerous advantages. The primary advantage of using lightweight is to reduce the dead load of the concrete structure, which allows the structural designer to reduce the size of carrying columns, footings and other load bearing elements. Furthermore, the reduced mass will reduce the lateral load that will be imposed on the structure during earthquakes, hence simplifying and reducing the lateral load carrying system. Structural light-weight concrete mixes can be designed to achieve similar strengths as normal weight concrete. The same is true for other mechanical and durability performance requirements. Structural lightweight concrete provides a more efficient strength-to-weight ratio in structural elements. In most cases, the marginally higher cost of lightweight concrete is offset by size reduction of structural elements, less reinforcing steel and reduced volume of concrete which result in lower overall cost. Light-weight foamed concrete is a new kind of Lightweight concrete, which combines the advantages of normal density concrete, cellular concrete and self-compacting concrete through partially replacing the normal weight aggregates with polystyrene foam, hence, leading to concrete unit weight reduction while maintaining adequate strength. The latter material can therefore be produced using standard methods familiar to the construction industry with a dry unit weight of 18.5 kN/m3, which in turn leads to dead load reduction of 15 – 20 % and the associated decrease in the structure's overall cost, hence, providing a feasible challenge to normal density concrete (NDC).

II. EXPERIMENTAL PROGRAM

The experimental program includes testing of three types of columns in order to perform two stages of loading, pure axial load and eccentric loads. The details of tested columns are as follows:

A. Column Group No. (1)

Rectangular columns (A1-A2) of effective cross section 100 x 200 mm, overall length 2000 mm, with longitudinal reinforcement 4 ϕ 8 mm in corners and 5 ϕ 6/m closed stirrups with spacing 20 cm and the additional reinforcement details are given in figure (1).

Dr. Eiad Hafiz Zahran, Associate Professor, Department of structural Engineering, Higher institute of engineering and technology, New Cairo Academy, Cairo, Egypt.

B. Column Group No. (2)

Square columns (B1-B2) of effective cross section 100 x 100 mm, overall length 2000 mm, with longitudinal reinforcement 4 ϕ 8 mm in corners and 5 ϕ 6/m closed stirrups with spacing 20 cm and the additional reinforcement details are given in figure (1).

C. Column Group No. (3)

Circular columns (C1-C2) of effective cross section diameter of 100 mm and overall length 2000 mm, with longitudinal reinforcement 4 ϕ 8 mm and 5 ϕ 6/m closed stirrups with spacing 20 cm and the additional reinforcement details are given in figure (1).

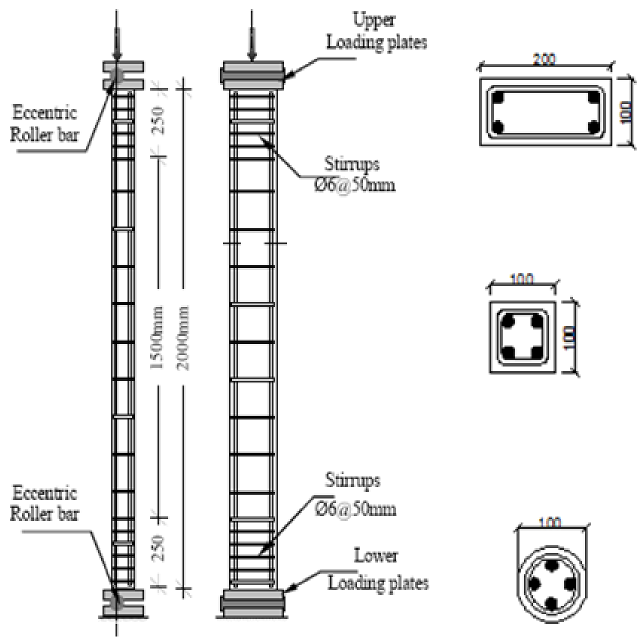


Fig.(1): Specimen concrete dimensions and reinforcement details

III. EXPERIMENTAL DETAILS

I. ***Characteristics of used materials***

The properties of the materials used for preparing lightweight concrete composites tested in this study are: aggregates, cement, silica fume, water, foam, super-plasticizer, and reinforcement steel.

Aggregates:

The fine aggregates used in this work were all of siliceous graded natural sand. It has a fineness modulus of 3.35 and apparent specific gravity of 2.62. Course aggregates used were all composed of siliceous gravel and having a general particle shape of a combination of round and sub –angular with max nominal size 10 mm and the surface texture is more or less smooth and uniform.

Cement:

The cement used in all of the experimental work was ordinary Portland cement of physical and chemical properties in compliance with E.S.S. 373, 1984.

Water:

Clean drinking fresh water free from impurities was used for mixing and curing.

Silica fume:

The silica fume used in all experimental work was ordinary silica fume.

Super plasticizer:

A high water reducer or a super-plasticizer was added to the concrete composites to improve the workability of the fresh composite and at the same time converse its compactness without increasing the water content. The super-plasticizer used in this study was of a liquid form under trade Name, ADDICRETE BVS which is in compliance with ASTM C494, 1982 of type V with doses about 2.8%. It permits a reduction of 24% of the water content in concrete mixture when used in these doses.

Reinforcing steel:

The longitudinal reinforcement of columns of diameter 8 mm was of high grade steel while and the 6 mm were of mild steel.

Mix Composition

The quantities required by weight for one cubic meter of fresh concrete for the lightweight columns are as given in table (1).

Table (1): Material quantities the lightweight concrete columns

Materials	**Quantities**
Cement kg/m3	450
Sand kg/m3	630
Gravel kg/m3	630
W/C Ratio	0.308
Plasticizer L/m3	13.5
Silica fume kg/m3	40

IV. PREPARATION OF SPECIMENS

Forms:

Wooden forms were designed and prepared to allow for simple and correct placing of concrete. The steel bars were tied with the stirrups forming reinforcement cages corresponding to that required for columns. Electrical strain gauges of 10 mm length and 120 ohm resistance were fixed on the steel bars, in order to follow the reinforcement strains during loading. The strain gauges were covered with silicon sealant to protect them during casting and consolidation of concrete. The forms were coated with a thin layer of oil to facilitate their removal after hardening of concrete. The reinforcement cages were then placed in the forms and lifted by small blocks to permit appropriate concrete cover.

Mixing and Curing

Dry materials were mechanically mixed in a drum mixer for two minutes then water and super-plasticizer were added to the mix and cast in the forms just after mixing. The batch consisted of 34 kg cement, 9.5 kg water, 48 kg sand, 48 kg gravel, 1 liter super-plasticizer and 0.38 kg foam with approximately three batches to cast each column. The cast concrete was then vibrated with an electrical needle vibrator and hence, the final concrete surface was smoothed. The forms were removed after 24 hours from casting and columns were moistened continuously with water for 7 days and kept in laboratory atmosphere until they were tested after 4 to 6 weeks. Standard specimens were prepared during casting columns to obtain the mechanical properties of the used concrete. These specimens consisted of 12 cube specimens

(15.8 cm side) and 2 cylindrical specimens (15 cm diameter and 30 cm height). The specimens were cast in layers and each layer was compacted by rod. After 24 hours, the specimens were demoulded and kept under water until they were tested. Six cubes and one cylinder were tested in compression to get the 7 days strength while the other cubes and cylinders were tested to get the 28 days compressive strength. Table (2) shows the average values of the obtained results.

Table (2): Mechanical properties of lightweight concrete mix

	Cube Strength		Cylinder Strength	
Time days	After 7 days	After 28 days	After 7 days	After 28 days
Strength N/mm2	18	24	12	19

V. EXPERIMENTAL AND ANALYTICAL RESULTS

A. LOADING OF COLUMNS

Two sides of each column are white painted, one day before testing, to facilitate the tracing of cracks during loading. At the day of testing, the column was mounted and adjusted in machine. The columns were all loaded in increments up to failure. The tested columns were instrumented to measure their mechanical behavior after each load increment using the following tools.

a. Strains: The concrete strains were measured using mechanical strains gauges (extensometer) of 50 mm gauge and 0.01 mm accuracy. The distance between demec points mounted on the painted sides of the specimen was measure in three rows. The main reinforcement strains were measured with the electrical strain gauges fixed on them. The electrical strain gauges were coupled to a strain indictor.

b. Lateral deflections: They were measured using 5 LVDT 100 mm capacity and 0.01 mm accuracy and were arranged to measure the deflection distribution throughout the column height.

c. Cracks: After each load increment the cracks are traced and marked on the painted sides of the specimen according to their priority of occurrence.

B. BEHAVIOR OF THE TESTED SPECIMENS

The six tested models behaved in a different manner and the following remarks were noticed:

- ***Cracking, Crack Pattern and Failure Load***

For the tested columns, the first crack for the eccentric rectangle column appeared at a load level about 0.7 of the ultimate load (the failure load) while for the eccentric square column the first crack appeared at a load level about 0.72 of the ultimate load, while the first crack for the eccentric circular column appeared at a load level about 0.66 of the ultimate load (the failure load). Table (3) shows the load at which the first crack appeared, the failure load and the eccentricity used for all specimens. Figures (3) to (8) show the (load-displacement) curves of the columns. Figures (9) to (11) shows the analytical shape of failure of the columns.

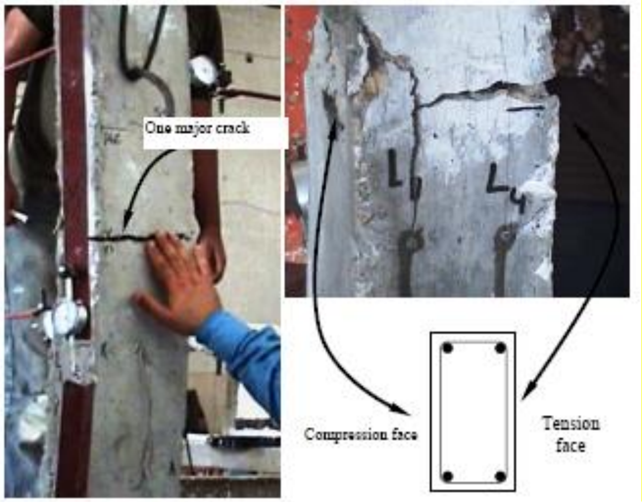


Fig.(2): Failure of Column A2

Table (3): Results of Column Loading Tests

Specimen No.	Eccentric (cm)	Cracking Load (kN)		Failure Load (kN)	
		Ansys	Exp.	Ansys	Exp.
A1	0	243	332	392	425
A2	2.5	133	152	190	218
B1	0	181	202	229	238
B2	2.5	80	102	103	140
C1	0	178	209	229	258
C2	2.5	81	80	113	120

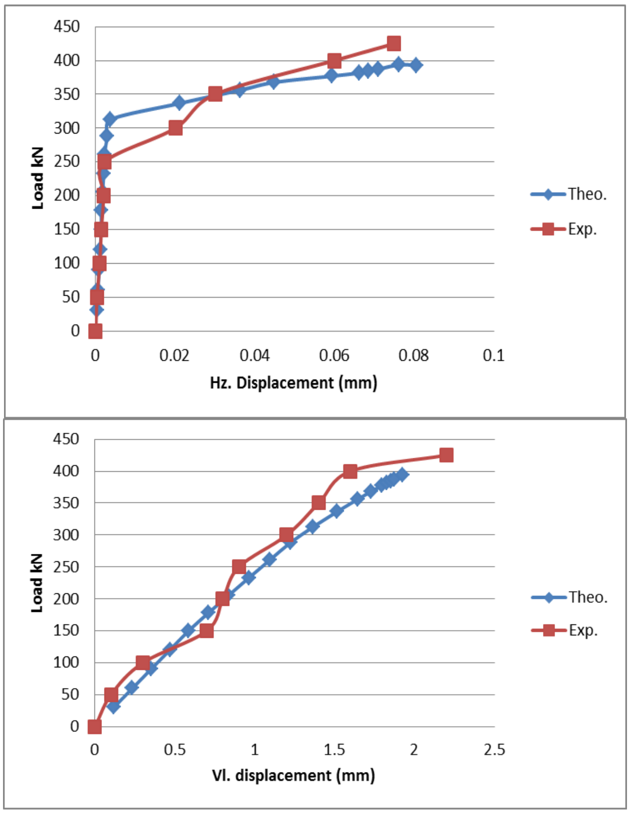


Fig.(3):Comparison between experimental and theoretical (load-Disp.) result in Column A1

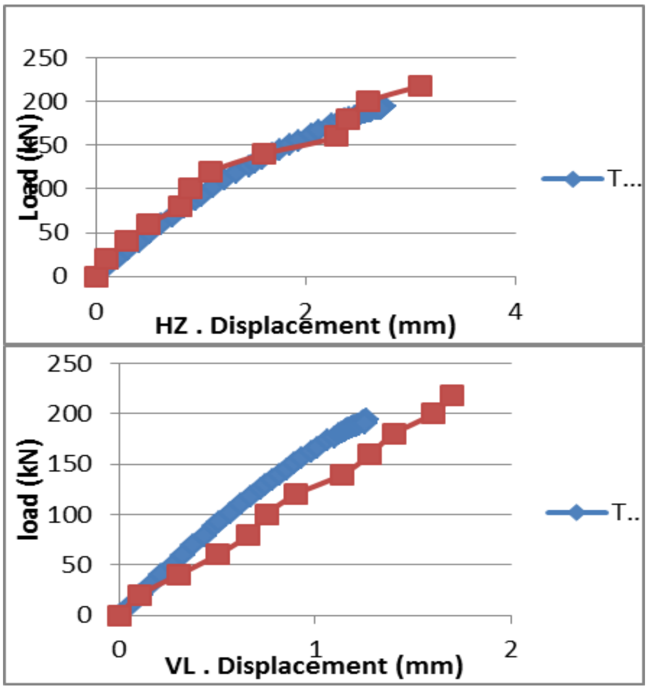


Fig.(4):Comparison between experimental and theoretical (load-Disp.) result in Column A2

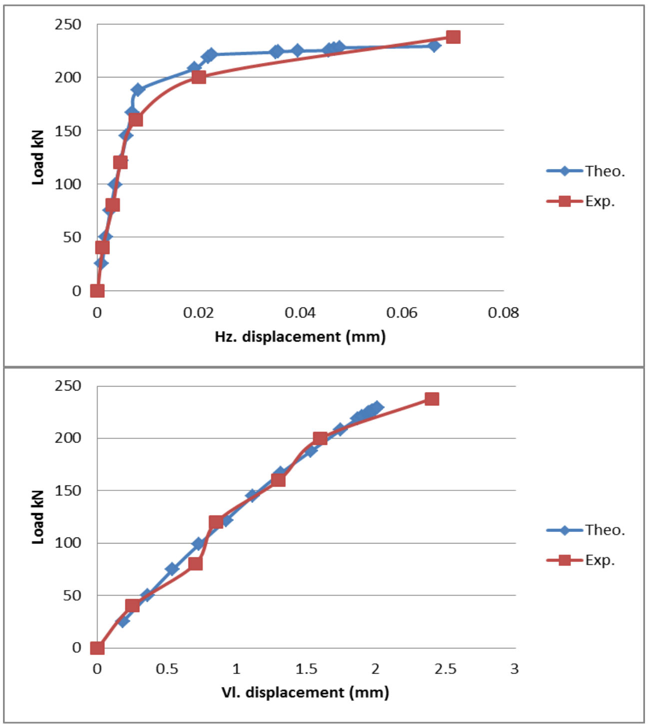
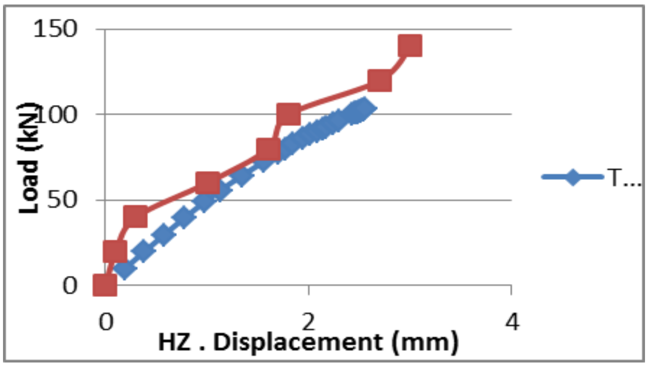


Fig.(5):Comparison between experimental and theoretical (load-Disp.) result in Column B1



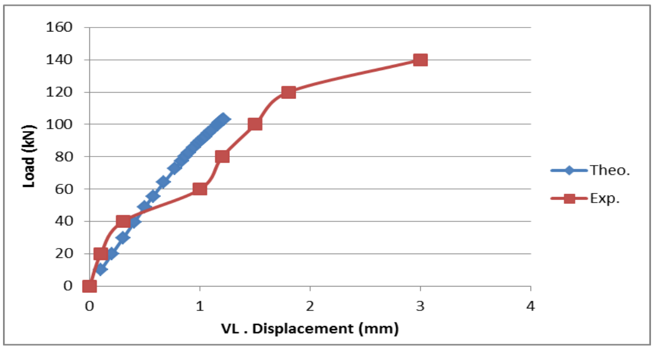


Fig.(6):Comparison between experimental and theoretical (load-Disp.) result in Column B2

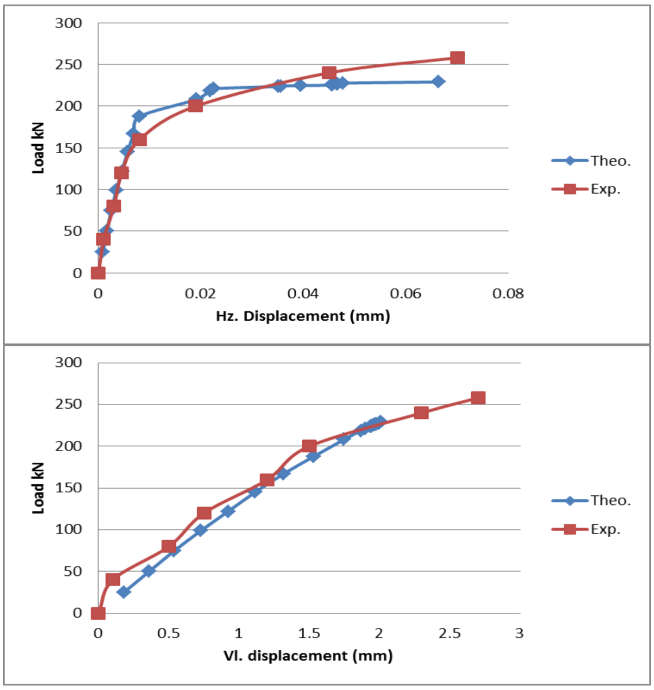


Fig.(7):Comparison between experimental and theoretical (load-Disp.) result in Column C1

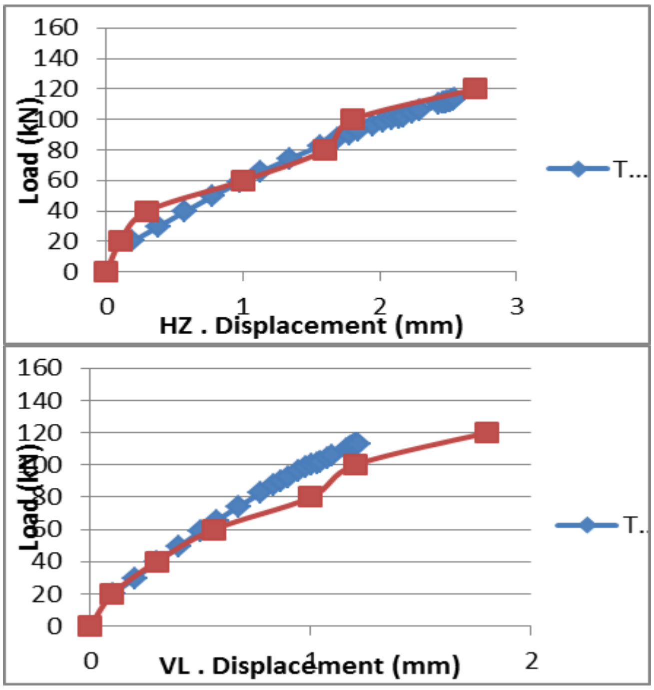


Fig.(8):Comparison between experimental and theoretical (load-Disp.) result in Column C2

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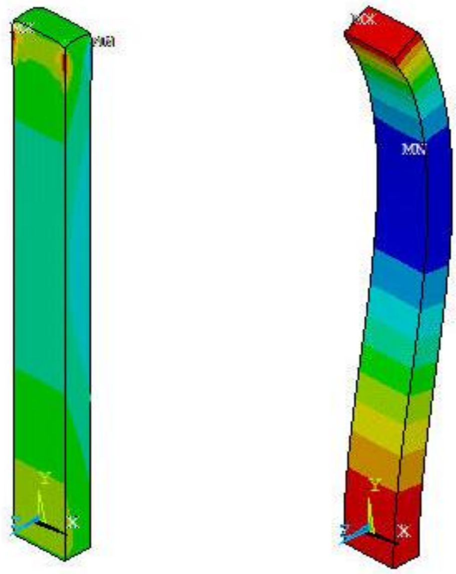

Fig.(9): Analytical shape of failure of columns A1 and A2

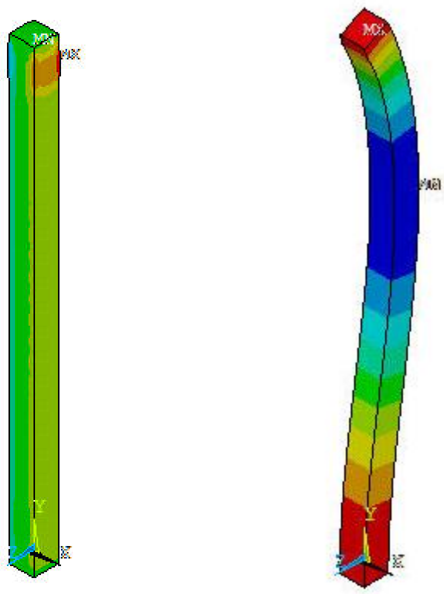

Fig.(10): Analytical shape of failure of columns B1 and B2

Fig.(11): Analytical shape of failure of columns C1 and C2

From the previous table and the mentioned figures the following marks can be included.

1- The ratio of first crack load to failure load for zero eccentricity columns is more than for eccentric column and this can be attributed to the difference of the behavior of lightweight concrete due to compression only and due to compression and moment.
2- For the eccentric columns (A2, B2 and C2) the first crack appeared in the lower middle of the columns and as a load increased, the cracks propagated upwards in almost a vertical manner.
3- It was the observed that all the columns tested have low ductility and this may be attributed to the high cube strength of the concrete used.

DEFLECTIONS

As mentioned before, central lateral deformations of the tested models were measured on each model to predict the deflected shape of the tested model. The experimental and analytical load central deflection curves, on tension side of all tested specimens, are shown in figures (3) to (8). From these figures, the following remarks could be concluded.

1- The horizontal load-deflection curves for models (A1, B1 and C1) were nearly linear at the early stages of loading (from zero up cracking of concrete), after which there was a bigger increase in deflection because of the great decrease in stiffness due to excessive cracking.
2- For all models, it was noticed that increasing eccentricity causes increase of central deflection and this can be attributed to the increase in moment acting on the models.

VI. CONCLUSIONS

From the Experimental specimens and the presented analytical model is promising obtained are summarized as follows:

1- The observed value of the first cracking loads for all values of load eccentricity (e/t) almost same with theoretical analysis.
2- On the basis of the test results, it is recognized that the concrete and the reinforcing bar strains conform closely to the plane strain distribution even in the case of biaxial bending.
3- The analytical analysis adopted herein to solve the load-deformation response of the column very well predicts the test behavior.
4- The ultimate load carrying capacity of a slender column is reduced by the additional eccentricity due to lateral deflections, even in a column having a length to depth ratio of 15.
5- In the case of square long columns, there is not much difference on ultimate loads of the columns of a circle cross section.

REFERENCES

[1] Amr H. Abd-Elazim Zaher (1995), "The failure behavior of high strength concrete beams", Ph.D. Thesis, Ain-Shams University.

[2] Chai, Y.H.; Priestly, M.J.N. and Seible, F., Seismic Retrofit of Circular Bridge Columns for *Enhanced Flexural Performance.* Struct. J., 1991. **88**(5): p.572-584.

[3] Etman, E.E. and A. Khalil, A., *Effect Of Corner Radius On The Behavior Of Strengthened R.C. Columns With Different Heights*. AICSGES, Fifth Alexandria International Conference on Structural and Geotechnical Engineering, Alexandria, 2003, Volume II, pp RC 345-360. Egypt.

[4] Formed Lightweight Concrete. ASTM C 567.

[5] Kayali, O.A. and Haque, M.N. “A new generation of structural lightweightconcrete,” ACI, SP-171, 1997, pp. 569-588.

[6] Khaled M. Ali (1998),"Behavior of steel reinforced concrete columns",M.Sc. Thesis, Ain-Shams University.

[7] MohdRojiSamidi, (1997). First report research project on lightweight concrete, UniversitiTeknologi Malaysia, Skudai, Johor Bahru.klj

[8] Priestly, M.J.N.; Seible, F.; Xiao, Y. and Verma, R., *Steel Jacket Retrofitting of Reinforced Concrete Bridge Columns for Enhanced Shear Strength-Part 1: Theoretic Consideration and Test Design.* ACI Struct. J., 1994a. **91**(4):p.394-405.

[9] Priestly, M.J.N.; Seible, F.; Xiao, Y. and Verma, R., *Steel Jacket Retrofitting of Reinforced Concrete Bridge Columns for Enhanced Shear Strength-Part 2: Test Results and Comparison with Theory.* ACI Struct. J., 1994b. **91**(5):p.537-551.

[10] Pessiki, S.; Harries, K.; Kestner, J.; Sause, R. and Ricles, J., *Axial behavior of reinforced concrete columns confined with FRP jackets. J. Compos. Constr.*, 2001. 5(4):p.237–245.

[11] Saadatmanesh, H.; Ehsani, M.R. and LI, M.W., *Strength and ductility of concrete columns externally reinforced with fiber composite straps*. *ACI Struct. J.*, 1994. **91**(4):p.443–447.

[12] Wael M. Montaser (2000),"Performance of reinforced high-strength concrete short columns under eccentric loads", M.Sc. Thesis, Ain-Shams University.

[13] Wang, Y.C. and Restrepo, J.I., *Investigation of concentrically loaded reinforced concrete columns confined with glass fiber reinforced polymer jackets*. ACI Struct. J., 2001. **98**(3):p.377–385